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1) Genotype x Environment interaction in soybean: I. Individual regression analysis

In this communication, the results obtained from the material given earlier (Gupta et al., 1981) on the basis of individual regression analysis by using Perkins and Jinks (1968) model, have been presented for different traits groupwise. In the individual regression analysis, genotypes having nonsignificant regression m.s. as well as remainder m.s. against error m.s. were described as exhibiting absence of genotype x environment (g x e) interaction, genotypes having regression m.s. significantly different from error m.s. were designated as showing predictable g x e (linear g x e) interaction, and genotypes having only significant remainder m.s. or significant regression m.s. not significantly different from significant remainder m.s. were categorized as genotypes showing unpredictable g x e (nonlinear g x e) interaction.

On the basis of this all 40 genotypes were classified into three groups and their distribution with respect to different groups of characters studied is given in Table 1.

Seed yield and its components. In this group of characters, none of the genotypes showed absence of g x e interaction. Majority of the genotypes (about 60% genotypes for pods per plant, pods per main stem and pod length; 80% for seed yield per plant and 92.5% for seeds per pod) exhibited predictable g x e interaction.

Seed quality traits. For percent laboratory germination, percent field emergence and percent hard seed, 10, 18 and 23 genotypes showed absence of g x e interaction; 20, 6 and 16 genotypes exhibited predictable g x e interaction; while 8, 10, 16 and 7 genotypes had unpredictable g x e interaction, respectively. For 100-seed weight and 100-seed volume, none of the genotypes exhibited absence of g x e interaction, 55% genotypes showed predictable g x e interaction. For seed density and seed specific gravity index, majority of the genotypes exhibited unpredictable g x e interaction.

Structural components. None of the genotypes showed absence of g x e interaction for primary branches per plant and nodes per main stem, while only a few genotypes (about 10%) did so for rest of the traits. More than 50% of the genotypes exhibited unpredictable g x e interaction for plant height, primary branches per plant and nodes per main stem. Approximately 80% of the genotypes exhibited predictable g x e interaction for internode length and petiole length.

Phenological traits. None of the genotypes exhibited absence of g x e interaction for these traits. Almost all the genotypes (97.5%) indicated predictable g x e interaction for days to maturity while about half of them (52.5%) did so for days to first flowering.

Physiological traits. Approximately 80% of the genotypes had predictable g x e interaction and 10% exhibited absence of g x e interaction for pod potential per node, the only character studied in this group.

Table 1. Distribution of 40 genotypes on the basis of presence (or absence) and nature of genotype x environment interaction for different groups of characters

Character	G x E absent	Predictable G x E	Nonpredictable G x E
Seed yield and its components			
Seed yield/plant (gm)	0	32	8
Pods/plant	0	25	15
Pods/main stem	0	23	17
Pod length (cm)	0	26	14
Seeds/pod	0	37	3
Seed quality traits			
Percent lab. germination	10	20	10
Percent field emergence	18	6	16
Percent hard seed	23	10	7
100-seed weight (gm)	0	22	18
100-seed volume (cc)	0	22	18
Seed density (gm/cc)	4	2	34
Seed specific gravity index	2	11	27
Structural components			
Plant height (cm)	2	15	23
Branches/plant	0	17	23
First internode length (cm)	4	32	4
Petiole length (cm)	6	33	1
Nodes/main stem	0	19	21
Phenological traits			
Days to first flowering	0	21	19
Days to maturity	0	39	1
Physiological traits			
Pod potential/node	3	33	4

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2) Genotype x Environment interaction in soybean: II. Joint regression analysis

The individual regression analysis has been given in the previous communication. In this article the results obtained from joint regression analysis (Table 1) according to Perkins and Jinks (1968) for all the groups of characters except leaf potential and leaf area where conventional g x e interaction analysis was done, are being presented. The method and materials and the layout of the experiment was the same as reported by Gupta et al. (1981). The groupwise results obtained are given below.

Seed yield and its components. In this group, joint regression analysis indicated that all the items in the ANOVA (mean sum of squares for genotypes, environments, genotype x environments, heterogeneity among regressions and heterogeneity among deviations) except remainder m.s. were significant for seed yield per plant, pods per plant and pods per main stem, while for pod length and seeds per pod, m.s. due to genotypes as well as due to environments were significant. This indicated that genotypic differences existed for all the attributes studied in this group. Significant environmental m.s. for all the traits indicated the diversity present among the environments studied. The m.s. due to g x e interaction was significant for all the traits except those for pod length and seeds per pod.

On partitioning the g x e interaction into linear and nonlinear components, heterogeneity among regression (linear portion of g x e interaction) was significant for seed yield, pods per plant and pods per main stem, while heterogeneity among deviations (nonlinear portion of g x e interaction) was not significant, when tested against pooled error m.s., indicating, thereby, the presence of only linear (predictable) g x e interaction.

Seed quality traits. Genotypic differences existed for all the traits studied in this group except percent field emergence. Diversity among environments was also present. All the traits except percent field emergence exhibited presence of g x e interaction. Linear g x e interaction was present for percent laboratory germination and percent hard seed, whereas for 100-seed volume, although linear g x e interaction was predominant, yet nonlinear g x e interaction was appreciable as indicated by significant heterogeneity among regression m.s. from significant remainder m.s. For 100-seed weight, seed density and seed specific gravity index, both linear and nonlinear g x e interactions were equally important.

Structural components. Genotypic differences existed for all the components studied except internode length. Environments studied also differed significantly from each other. All the components except internode length exhibited the presence of g x e interaction. Linear g x e interaction was recorded for petiole length and nodes per main stem, whereas for primary branches per plant, though linear g x e interaction was present, an equal amount of nonlinear g x e interaction was also observed. However, for plant height, absence of linear g x e interaction, and the presence of nonlinear g x e interaction was observed as indicated by nonsignificant heterogeneity among regression m.s. and significant remainder m.s. from error m.s.

Phenological traits. For both the traits studied in this group, namely, days to first flowering and days to maturity, joint regression analysis indicated significant differences among genotypes and environments and presence of g x e interaction. Linear as well as nonlinear g x e interaction were equally important for both the traits.

Table 1. Joint regression/ genotype x environment/ interaction analysis in respect to different groups of characters

Source of variation	Mean sum of squares: Genotypes	Environments (joint regression)	Genotypes x environments (GxE)	Heterogeneity between regression	Remainder	Error σ^2e
1	2	3	4	5	6	7
<u>Seed yield and its components</u>						
Seed yield/plant (gm)	17.92*	2726.01*	9.50*	11.40*	8.87*	6.8855
Pods/plant	239.78*	13629.62*	86.36*	140.56	68.29	62.9762
Pods/main stem	28.07*	829.92*	6.58*	11.00*	5.11	4.5592
Pod length (cm)	0.22*	11.77*	0.087	0.11	0.08	0.0865
Seeds/pod^{+}	0.076*	6.45*	0.20	0.026	0.016	0.277
<u>Seed quality traits</u>						
Percent lab germination	130.80*	3631.67*	90.17	122.75*	79.31	71.8709
Percent field emergence	260.27	1741.64*	175.20	154.94	181.96	193.2397
Percent hard seed	17.45*	202.34*	11.69*	30.32*	5.48	5.8728
100-seed weight (gm)	7.92*	181.04*	0.89*	1.05*@	0.84*	0.4305
100-seed volume (cc)	5.30*	132.20*	0.61*	0.81*@@	0.54*	0.2861
Seed density (gm/cc)	0.00071*	0.0031*	0.00025*	0.00027*@	0.00024*	0.00007
Seed specific gravity index	591.52*	7146.03*	100.53*	119.27*@	94.28*	58.7431
<u>Structural components</u>						
Plant height (cm)	179.30*	1322.77*	23.66*	19.27	25.12*	17.4215
Branches/plant	2.63*	116.58*	0.96*	1.14*@	0.90*	0.5183
First internode length (cm)$^{+}$	0.50	50.32*	0.35	0.41	0.32	0.3809

Table 1. Continued

1	2	3	4	5	6	7
Structural components (contd.)						
Petiole length (cm)[‡]	20.69*	2523.96*	16.96*	24.85*	9.06	8.7039
Nodes/main stem	6.01*	230.66*	0.90*	1.04*	0.85	0.6865
Phenological traits						
Days to first flowering[‡]	24.93*	2381.87*	6.26*	7.15*@	66.18*	3.0619
Days to maturity	14.05*	3740.67*	3.29*	3.41*@	3.28*	1.4869
Physiological traits						
Pod potential/node[+]	0.20	36.16*	0.18	0.29*	0.12	0.1523
Leaves potential/node[§]	170.26*	30599.66*	54.77*	--	--	2.5215
Leaf area[§]	55.2248*	2470.8645*	57.0367*	--	--	3.3361

*Significant at the 5% level.

*@Heterogeneity between regressions significant against error M.S. but not against significant remainder M.S.

*@@Heterogeneity between regressions significant against error M.S. as well as against significant remainder M.S.

[+]Data analyzed over 4 locations.

[‡]Data analyzed over 3 locations.

[§]Data analyzed over 2 locations.

Degrees of freedom for joint regresson/GxE interaction analyses

Source of variation	Characters			
	Analysis over 5 environments	Analysis over 4 environments	Analysis over 3 environments	Analysis over 2 environments
Genotypes	39	39	39	39
Environments (joint regression)	4	3	2	1
Genotypes x environments (G x E interaction)	156	117	78	39
Heterogeneity between regressions	39	39	39	---
Remainder	117	78	39	---
Error	195	156	117	78

Physiological traits. Among the three physiological traits studied, genotypic differences were significant for leaf area and leaf potential per plant but not significant for pod potential per node. However, g x e interaction was present for all the three traits. Linear g x e interaction was present for pod potential per node, whereas for leaf área and leaf potential per plant, nature of g x e interaction could not be studied as these were recorded only in two of the environments.

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3) Association among productivity, responsiveness and stability for different groups of traits in soybean

In India, soybean adaptability trials have revealed that, in order to stabilize yield and popularize soybean cultivation, breeders must look for genotypes with good germinability and wider adaptability under diverse geographical and climatological situations (Singh, 1976). Prospects of developing different genotypes having varying degrees of adaptability would depend to some extent on the relationship between various adaptability parameters; namely, di (additive genetic effect-productivity), βi (genotypic regression - a measure of responsiveness), $S_{\bar{d}}^{2}$ (deviation from regression - a measure of stability). This has been attempted in the present study on the same material as reported earlier (Gupta et al., 1981) by working out the correlations over all the 40 genotypes between the three parameters which were calculated as per Perkins and Jinks (1968) taken in pairs (Table 1).

As per the results (Table 1) there appears to be a strong positive association between mean performance of a variety or its additive genetic effect (di in Perkins and Jinks, 1968 model) and ability to respond to a better environment which is particularly marked in case of seed yield per plant, pods per plant, pods per main stem, plant height, primary branches, petiole length, nodes per main stem, days to maturity and pod potential per node. Such a positive correlation for majority of yield components and structural components has also been documented earlier in different crops (Eberhart and Russell, 1966; Perkins and Jinks, 1968; Breese, 1969; Gupta et al., 1974; Langer et al., 1979). However, in soybean, on this association conflicting results have been reported. Verma et al. (1972) have reported positive association for majority of yield and structural components, but no association for days to maturity, whereas Smith et al. (1967), Tsai et al. (1967) and Walker and Fehr (1978) have reported apparently no association between mean yield and responsiveness. Moreover, this association for petiole length, nodes per main stem and pod potential per node has been documented only for the first time in the present study.

In respect to all the seed quality traits, namely 100-seed weight, 100-seed volume and seed density, though apparently there is a positive correlation between 'di' and 'βi' but it is not significant. For seed specific-gravity index, absence of such a relationship has been reported in soybean by Verma et al. (1972) and for some of the quality characters in chickpea by Gupta et al. (1974).

Among seed yield and its components, there is no apparent relationship between 'di' and 'βi' for pod length and seeds per pod and same is the case for days to first flowering. In literature, a significant positive association has been reported for days to first flowering, 100-seed weight, and pod length, but no association for days to maturity, which is in contradiction with the present findings but for seeds per pod and seed specific-gravity index, the present results are in conformation with earlier reports (Verma et al., 1972).

There is no apparent association of stability parameter S^{-2}_{d} with mean performance (di) and responsiveness (βi) for majority of the characters studied including seed yield, though the trend is weak and becomes positively significant only in case of pods per plant, pods per main stem, pod length and primary branches per plant with respect to 'di' and 'S^{-2}_{d}', and it becomes positively significant for nodes per main stem and negatively significant for pod length, 100-seed weight and primary branches per plant with respect to βi and 'S^{-2}_{d}'. The information on the association of 'S^{-2}_{d}' with di and βi, in the literature for soybean is not available. However, more or less similar association, as recorded in present study, has been reported in chickpea by Gupta et al. (1974) and in oats by Langer et al. (1979). Hence, these associations reveal that, for major yield components, structural components and maturity, a breeder can simultaneously select both for high yield and high responsiveness to changing environments. For seed quality traits, also, situation is equally good, because one can have specific combination of desired nature, like high seed quality and least responsive or high seed quality and average responsive or high seed quality and above-average responsiveness. Independent behavior of 'S^{-2}_{d}' in relation to other adaptability parameters provides a happier situation for combining high stability with high productivity (di) and high productive response (βi) for majority of economic traits, e.g., seed yield, seed density and seed specific-gravity index. However, the positive association of 'di' and 'S^{-2}_{d}' with respect to pods per plant, pods per main stem, pod length and primary branches per plant has to be viewed cautiously. The negative association between 'βi' and 'S^{-2}_{d}' for 100-seed volume is useful from a breeding point of view.

Table 1. Estimates of correlation coefficients between various adaptability parameters (di, βi and S^{-2}_{d}) for different groups of characters

Characters	Correlation between		
	di and βi	di and S^{-2}_{di}	S^{-2}_{di} and βi
Seed yield and its components			
Seed yield/plant (g)	0.82*	0.04	-0.12
Pods/plant	0.86*	0.37*	0.29
Pods/main stem	0.88*	0.42*	0.21
Pod length (cm)	-0.07	0.38*	-0.32*
Seeds/pod	0.10	0.14	0.10
Seed quality traits			
100-seed weight	0.020	0.01	-0.26
100-seed volume	0.20	-0.09	-0.37*
Seed density	0.13	0.10	-0.06
Seed specific gravity index	0.20	0.02	0.03
Structural components			
Plant height (cm)	0.54*	0.18	-0.16
Primary branches/plant	0.71*	0.41*	0.35*
Petiole length (cm)	0.87*	0.09	0.18
Nodes/main stem	0.71*	0.21	0.39*
Phenological traits			
Days to first flowering	0.21	0.19	-0.08
Days to maturity	0.77*	0.11	0.06
Physiological traits			
Pod potential/node	0.48*	0.26	0.06

*Significant at 5% level.

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4) Genetic control of productivty, responsiveness and stability for different groups of traits in soybean

In order to breed adaptable varieties, selection is to be based on the above three parameters of adaptability simultaneously, for achieving the desired objectives. After understanding the association between these, it is imperative to have information on the gene action or genetic architecture of these three parameters, because in a self-pollinated crop like soybean where end product is homozygous and homogeneous population, selection will be fruitful only if gene action is of additive or additive x additive nature.

In the present study, an attempt has been made to infer the genetic control of mean performance (di-productivity), responsiveness and stability with respect to each different group of characters studied, on the basis of segregation pattern observed among 36 F_4-derived lines, of the cross Soybean Pb.1 x D 60-9647, in relation to their parents. The other details of the experiment were the same as reported earlier (Gupta et al., 1981), except that the parameters of productivity (di), responsiveness (βi) and stability (S^{-2}_{d}) were estimated as per Perkins and Jinks (1968a,b). It can be seen from Table 1 that in general for seed yield and its components, performance appears to be under additive type of gene action as the majority of the segregants are having parent-dependent mean performance. The occurrence of transgressive segregants, having mean performance more than the parents for most of the yield components might be due to higher order of additive x additive epistatic interaction. Such a genetic control of mean performance has also been earlier documented in soybean (Leffel and Weiss, 1958; Leffel and Hanson, 1961, Paschal and Wilcox, 1975; Bhatade et al., 1977).

The segregants for this group of traits (seed yield and its components) have also shown parent-dependent responsiveness, as indicated by very high frequency of segregants having average responsiveness when the two parents are also average responsive. For this parameter (βi) also, seed yield and its components have thrown transgressive segregants though frequency is low as compared to mean performance. From this, it can be inferred that genetic control for responsiveness is also of additive x additive nature.

It is interesting to note that, for seed yield and its components, the segregants exhibit parent-dependent stability (S^{-2}_{d}). For seed yield per plant and seeds per pod, both the parents were having high stability and more than 75% of the segregants have also exhibited stability. For pods per main stem, both the parents were unstable and it is interesting to see that for this character, approximately 50% of segregants are stable and 50% are unstable. For pods per plant and pod length, where only one of the parents is stable, approximately 60% of the segregants exhibit stability. For this parameter (S^{-2}_{d}) though genetic control appears to be predominantly additive for seed yield and seeds per pod but for pods per plant, pods per main stem and pod length, genetic control might be due to additive, dominance and epistatic interactions as well. Therefore, it appears that at least selection is likely to be effective for all the three parameters of adaptability for seed yield and seeds per pod, a character of fitness.

For seed quality traits, parent-dependent mean performance and responsiveness observed for segregants indicate the predominant role of additive gene action. Transgressive segregants are apparent particularly for seed specific-gravity index. However, responsiveness for seed specific-gravity index appears to be under predominantly dominant type of gene action, as more than 90% of the segregants have shown average responsiveness as possessed by one of the parents. For seed quality traits, also, stability (S^{-2}_{d}) appears to be under complex genetic control. However, for percent laboratory germination and percent hard seed, stability appears to be due to dominance as 90% of the segregants have stable behavior as shown by one of the parents. Therefore, for percent laboratory germination, selection may be effective for the three parameters, but for other seed quality traits, though selection might be profitable for mean performance and responsiveness but may not be so for high stability.

For structural, phenological and physiological traits also, performance and responsiveness appear to be parent-dependent, indicating thereby additive type of genetic control but stability parameter seems to be under complex genetic control. In literature, at least for soybean, the information on genetic control of responsiveness and stability parameter is limited except Oka (1973), where he has depicted yield stability as genotypic specific in some of Taiwanese varieties. However, some reports are available on the genetic control of mean performance with respect to some yield and developmental components but for germinability relevant information is not available (Leffel and Weiss, 1958; Weber et al., 1970; Paschal and Wilcox, 1975; Srivastava et al., 1978).

Some studies reported on other crops show that responsiveness and stability, at least to some extent, are under genetic control (Perkins and Jinks, 1968, a & b; Bucio-Alanis et al., 1969; Paroda and Hays, 1971) and the mean performance and linear sensitivity can be predicted successfully from one generation to another of the same cross, and it has been actually observed in the present study, too, with respect to various characters. Gupta (1971) in chickpea and Bains (1976) in wheat have also shown parent-dependent mean performance, responsiveness and stability in segregating generations.

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Table 1. Pattern of segregation with respect to productivity (di), responsiveness (βi) and stability (S^{-2}_{d}) of 36 F_4-derived lines in relation to their parents

Characters	Productivity					Responsiveness					Stability			
	Parental		Distribution of segregants			Parental		Distribution of segregants			Parental		Distribution of segregants	
	P_1	P_2	BA	A	AA	P_1	P_2	BA	A	AA	P_1	P_1	Stable (.)	Unstable (+)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Seed yield and its components														
Seed yield/plant (g)	A	A	1	32	3	A	A	0	34	2	.	.	26	10
Pods/plant	A	A	4	29	3	A	A	2	32	2	.	+	23	13
Pods/main stem	BA	A	5	24	7	A	A	1	31	4	+	+	17	19
Pod length (cm)	A	A	3	29	5	A	A	2	34	0	.	+	22	14
Seeds/pod	A	A	5	21	10	A	BA	1	32	3	.	.	34	2
Seed quality traits														
Percent laboratory germination	A	A	2	33	1	A	A	1	33	2	.	+	27	9
Percent hard seed	A	A	0	31	5	A	A	6	24	6	+	.	29	7
100-seed weight (g)	BA	AA	6	21	9	A	A	0	35	1	+	+	12	24
100-seed volume (cc)	BA	AA	5	22	9	A	A	0	35	1	+	+	14	22
Seed density (g/cc)	A	AA	5	29	2	A	A	2	33	1	+	+	7	29
Seed specific gravity index	A	A	8	22	6	BA	A	2	33	1	.	.	11	25
Structural components														
Plant height (cm)	A	A	7	24	5	A	A	1	34	1	+	.	15	21
Primary branches/plant	A	A	3	27	6	A	A	2	31	3	+	.	12	24
Petiole length (cm)	A	A	1	33	2	A	A	5	27	4	.	.	34	2
Nodes/main stem	A	A	7	20	9	A	A	1	33	2	+	+	16	20
Phenological traits														
Days to first flowering	AA	BA	11	15	12	A	A	1	34	1	.	.	19	17
Days to maturity	A	A	5	27	4	A	A	1	34	1	+	+	14	22

Table 1. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Physiological traits														
Pod potential/node	A	A	2	33	1	A	A	2	30	4	.	.	32	4

BA Below average
A Average
AA Above average
. Stable
+ Unstable

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5) Factor analysis in F_2 generation of soybean crosses

Factor analysis is a technique of reducing a large number of correlated variables to a few main factors. It has been resorted to to overcome the limitations of univariate methods of analysis like correlations, path-coefficient and regression analysis (Wright, 1960; Walton, 1972). Besides, Moreno and Cubero (1978) have used it for estimating diversity. This paper purports to report findings of factor analysis in soybean crosses to know important traits for yield selection and diversity among crosses.

Materials and methods: The F_2 populations of soybean crosses 'Hill' x 8-3, 'Davis' x 8-3, 'Lee' x 8-3, and 'Semmes' x 8-3, along with the parents, were grown in a randomized block design with four replications at the Indian Agricultural Research Institute, New Delhi. The varieties used as female parents are medium-tall, except Semmes (tall), and adapted in the north Indian plains and hills, whereas the common male parent, a tall variety, gives better performance in the southern parts of the country. Each plot (5m x 3m) had row-to-row and plant-to-plant spacing of 45 and 5 cm, respectively. Data on plant height, branches/plant, pod clusters/plant, pods/plant and seed yield/plant were recorded from 50 randomly selected plants from each replication. The data were tested for the existence of variability and significant traits were correlated in all possible combinations at phenotypic level. These correlations were used for factor analysis through principal component method, as suggested by Harman (1968). The analysis was terminated after the factors accounting for more than 90% variability were extracted.

Results and discussion: Phenotypic correlations (Table 1) indicated that correlations among various traits resembled across crosses except plant height in Semmes x 8-3 cross, which were not significant. The results showed that in medium-tall x tall populations improvement of seed yield and yield components is likely to prove effective with the selection of taller plants. Branches, pod clusters and pods/plant showed significant correlation with seed yield/plant in all the crosses.

Table 1. Phenotypic correlations in the F_2 generation of soybean crosses

Character	Cross	Branches/ plant	Pod clusters/ plant	Pods/ plant	Seed yield/ plant (g)
Plant height (cm)	Hill x 8-3	0.373*	0.583*	0.422*	0.343*
	Lee x 8-3	0.282*	0.482*	0.372*	0.294*
	Davis x 8-3	0.328*	0.405*	0.256*	0.287*
	Semmes x 8-3	0.125	0.107	0.129	0.136
Branches/plant	Hill x 8-3		0.795*	0.737*	0.640*
	Lee x 8-3		0.782*	0.719*	0.650*
	Davis x 8-3		0.721*	0.662*	0.446*
	Semmes x 8-3		0.757*	0.676*	0.604*
Pod clusters/plant	Hill x 8-3			0.866*	0.722*
	Lee x 8-3			0.868*	0.745*
	Davis x 8-3			0.901*	0.692*
	Semmes x 8-3			0.886*	0.833*
Pods/plant	Hill x 8-3				0.830*
	Lee x 8-3				0.838*
	Davis x 8-3				0.694*
	Semmes x 8-3				0.827*

*Significant at the 1% level.

Table 2. Factor loadings in soybean crosses

Character	Hill x 8-3 Factors I	Hill x 8-3 Factors II	Lee x 8-3 Factors I	Lee x 8-3 Factors II	Davis x 8-3 Factors I	Davis x 8-3 Factors II	Semmes x 8-3 Factors I	Semmes x 8-3 Factors II
Plant height	0.599	-0.344	0.516	-0.331	0.478	-0.252	0.153	-0.109
Branches/plant	0.810	0.281	0.818	0.290	0.491	0.401	0.822	-0.219
Pod clusters/plant	0.949	0.063	0.808	0.137	0.999	0.355	0.936	0.153
Pods/plant	0.881	0.271	0.902	0.309	0.933	0.401	0.915	0.258
Eigen value	2.724	0.275	2.555	0.307	2.340	0.511	2.412	0.150
Explained variation (%)	68.111	6.875	63.884	7.697	58.500	12.778	60.312	3.745

Factor analysis (Table 2) indicated that plant height, branches/plant, pod clusters/plant and pods/plant recorded their highest factor loadings in all the crosses in Factor I. The only exception was Semmes x 8-3 (tall x tall), where height was not important for the improvement of the yield. It appears that, in this cross, height is being affected by some other factor. The first factor recorded the highest factor loading for all the traits under study in all the crosses, indicated their overwhelming importance over other traits. Though no weightage was given to yield in this analysis, all the crosses indicated that all yield components were affected by the most important factor, i.e., Factor I. The present study indicated that minimum of 0.282** correlation among the traits was affected by a single factor. In case of Factor I, higher loadings were in favor of direct yield components (pods/plant and pod clusters/plant) and the lower loadings were in favor of growth traits (plant height and branches/plant), indicating that this factor was essentially related to the yield potential of plants. A comparison of the factor loadings in different crosses revealed variation in the size of the loadings although the composition of the variables in this factor remained essentially the same in all the crosses.

After the extraction of the first factor, the second factor did not appear to affect any trait except moderate effect on Davis x 8-3. In general, two factors accounted for 64-75% of the communality (proportion of total variance for phenotypic correlation matrix) in all the crosses. The results indicated that, even with a smaller number of the variables included in the study, factor analysis was potent in grouping four correlated variables into two factors. For the plant breeder, such information may well assist both by increasing his understanding of the relative importance of the yield components and growth traits and by helping to determine the nature and sequence of the traits for which the selections were to be made in his breeding program.

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6) Effect of environment and cropping system on the coefficients of variability for seed yield, quality, structural, phenological and physiological traits in soybean

Introduction. In the present investigation, the results obtained on the effects of environment and cropping system on the parameters of genetic variability for seed yield, quality, structural, phenological and physiological traits in soybean have been presented.

Materials and methods. The material, experimental design and characters studied were the same as reported by Gupta et al. (1981a). The data were further analyzed as per Johnson et al. (1955) for estimating various parameters of variability in different environments and cropping systems.

Results and discussion. Estimates of coefficient of variation at genotypic and phenotypic levels for different groups of characters over environments and cropping systems are given in Table 1.

Effect of cropping system. For seed yield per plant, genotypic, as well as phenotypic coefficients of variation were more in Palampur intercropping than in Palampur monoculture. For pods per plant, coefficients of variation (PCV and GCV both) were almost at par in the two cropping systems. For other three yield components, namely, pods per main stem, pod length and seeds per pod, GCVs were higher in case of Palampur monoculture than in Palampur intercropping, but converse was true for PCVs.

Among seed quality traits, for germination indices, percent laboratory germination, percent field emergence and percent hard seed, both PCV as well as GCV were higher in intercropping except percent hard seed where PCV was more in monoculture. Both for 100-seed weight and 100-seed volume, GCV and PCV were reduced in intercropping system, reduction being more in GCV. For seed density, GCV was more in monoculture but PCV was high in intercropping. For seed specific gravity index, estimates of GCV and PCV were larger in monoculture than in intercropping system.

Among structural components, GCV was substantially reduced in intercropping for primary branches per plant, first internode length and nodes per main stem. Both GCV and PCV were reduced for plant height in intercropping, though magnitude of reduction was low. PCV was also low in intercropping for other three traits except for primary branches per plant, where it was more. For days to maturity, GCV and PCV, both, were higher in monoculture than in intercropping. Drastic reduction was observed for the estimate of GCV for pod potential per node in intercropping but PCV was higher.

Effect of environment. As reported earlier (Gupta et al., 1981a), the environments sampled were varying with respect to altitude, and other climatic factors like rainfall and temperature. It can be seen from Table 1 that, in lower altitude (Kangra), GCV was considerably increased, while at Katrain, which is at a higher elevation, considerable reduction in the GCV was observed for seed yield. However, the PCV remained more or less stable over environments. For other seed yield components, namely pods/plant, pod length and seeds/pod, though PCV remained unchanged irrespective of altitude except with slight upward value in lower altitude, the GCV fluctuated considerably over environments. However, among seed yield components, pods per main stem was the least influenced by environments with respect to GCV.

In case of seed quality attributes, the effect of environment on both GCV and PCV was more pronounced in case of percent hard seed, specific gravity index, percent germination, whereas the estimates of other traits were least influenced. Among seed yield and seed quality components, a high magnitude of GCV was observed for percent hard seeds, specific gravity index and pods per main stem, in order.

In case of structural components, the magnitude of both GCV and PCV remained more or less stable over environments with the exception of primary branches per plant and petiole length. The PCV was enhanced at higher altitudes for primary branches, whereas it was reduced for petiole length.

In phenological traits, days to first flower exhibited stability for GCV over environments. At higher altitude, however, the estimates of these coefficients were comparatively reduced for days to maturity. For pod potential per node, the GCV estimates were drastically reduced at higher altitude, whereas PCV estimates were not influenced much. Among structural, phenological and physiological traits, petiole length, plant height, primary branches, exhibited comparatively high GCV estimates.

Conclusion. In general, both altitude and cropping system were found to influence the coefficients of variability both at phenotypic and genotypic level for different groups of traits in soybean. In the absence of limited reports available, on the influence of environments on the coefficient of variability, the above information would be valuable in breeding programs.

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Table 1. Estimates of coefficients of variation (c.v.) at genotypic and phenotypic levels for different groups of characters over environments

Characters		Environments				
		Palampur (mono-culture)	Palampur (inter-cropping)	Solan	Katrain	Kangra
Seed yield and its components						
Seed yield/ plant (gm)	G	15.66	21.75	18.20	4.99	27.41
	P	31.84	49.27	29.60	31.80	35.35
Pods/plant	G	9.99	10.93	25.76	18.57	7.52
	P	33.75	32.73	33.08	29.31	46.47
Pods/main stem	G	21.86	0.61	25.88	25.68	32.12
	P	31.72	37.41	35.53	29.57	58.49
Pod length (cm)	G	5.72	0.93	6.04	4.99	4.90
	P	10.36	21.51	8.79	8.51	7.56
Seeds/pod	G	4.54	2.04	4.09	--	5.52
	P	10.18	19.73	10.35	--	9.74
Seed quality traits						
Percent lab germination	G	1.69	5.54	3.49	9.62	6.87
	P	6.98	25.90	12.35	18.72	11.81
Percent field emergence	G	10.12	18.99	0.08	0.06	14.34
	P	49.29	67.29	48.56	44.80	49.35
Percent hard seed	G	70.50	138.75	149.79	81.99	82.72
	P	275.35	215.07	291.99	176.13	130.93
100-seed wt. (gm)	G	9.54	6.11	7.79	9.73	8.12
	P	10.79	9.41	8.64	11.03	10.69
100-seed volume (cc)	G	9.21	6.41	7.78	9.90	7.77
	P	10.56	9.55	8.65	11.04	10.19
Seed density (gm/cc)	G	1.33	1.29	1.15	1.59	1.44
	P	1.61	1.74	1.60	1.76	1.71

Table 1. Continued

Characters		Environments: Palampur (mono-culture)	Palampur (inter-cropping)	Solan	Katrain	Kangra
Seed specific gravity index	G	53.97	20.65	38.09	39.26	30.72
	P	69.34	37.75	56.65	46.52	37.08
<u>Structural components</u>						
Plant height (cm)	G	10.06	8.51	15.90	15.57	9.44
	P	16.91	16.53	19.19	17.79	16.45
Primary branches/ plant	G	11.34	1.23	12.49	12.34	22.57
	P	19.52	33.53	20.53	21.00	29.91
First inter-node length (cm)	G	4.65	0.84	0.49	--	5.30
	P	19.63	16.26	18.42	--	16.18
Petiole length (cm)	G	--	0.23	17.93	7.25	--
	P	--	19.55	28.16	13.39	--
Nodes/main stem	G	6.59	2.05	11.52	9.15	10.48
	P	13.16	12.10	15.56	11.31	12.92
<u>Phenological traits</u>						
Days to first flowering	G	7.18	--	7.85	--	6.49
	P	7.41	--	8.91	--	6.61
Days to maturity	G	1.93	1.50	1.58	0.51	2.64
	P	2.05	1.89	3.17	1.65	2.74
<u>Physiological traits</u>						
Pod potential/ node	G	10.23	1.52	0.81	--	17.72
	P	18.52	25.30	21.86	—	25.77

G denotes c.v. at genotypic level.

P denotes c.v. at phenotypic level.

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7) Consistency of heritability estimates over environments and cropping systems for different groups of traits in soybean

Introduction. Though numerous reports are available on heritability estimates from individual environment, yet information on consistency of heritability over environments is meager (Byth et al., 1969). An attempt has been made in the present communication to understand the influence of environments and cropping system on the heritability estimates in soybean.

Materials and methods. The materials and experimental design were same as reported by Gupta et al. (1981). Heritability estimates (broad sense) were calculated as ratio of genotypic variance to phenotypic variance, for different groups of traits over environments.

Results and discussion. Heritability estimates (broad sense) obtained from different environments and under intercropping system where soybean genotypes were raised in association with maize, are given in Table 1. As indicated above, there are very few reports on soybean on the influence of environment on heritability. Byth et al. (1969) evaluating genetically homogeneous lines obtained from two crosses in soybean, for nine characters in three environments, observed that heritability was relatively consistent for all traits except seed yield where heritability was enhanced under favorable growth conditions and reduced when moisture stress was alleviated. As the experimental material in the present study consisted of 40 entries representing F_4 derived lines of an intervarietal cross, and four standard pure line varieties, it will be interesting to examine the results obtained on heritability estimates incorporated in Table 1. Among all the traits studied, days to first flowering showed consistently highest heritability across environments.

Heritability for seed yield was high at lower elevation (Kangra) and at higher elevation (Solan, Palampur and Katrain) it was so reduced that at Katrain, the genetic variation was not significant. Under intercropping system at Palampur, the heritability was reduced as compared to monoculture system. The present results are contrary to those reported by Byth et al. (1969), because, while evaluating the same material, Gupta et al. (1981) reported Solan and Katrain as the favorable environments and Palampur monoculture as well as intercropping and Kangra as unfavorable. Therefore, the present results indicate that there is no relationship between heritability estimates and environmental status and there was a considerable inconsistency in heritability estimates for yield over environments. More or less similar situation was observed with respect to consistency of heritability and environmental status for pods per plant, but in this case heritability was low at the lower elevation (Kangra). For pods/main stem, pod length and seeds/pod, though, there was not much influence of location on consistency of heritability estimates, yet there was drastic influence of intercropping system on heritability estimates as can be seen from Table 1. For these traits also, there was no apparent relationship of heritability estimates with environmental status.

Among seed quality attributes, the influence of altitude on heritability was more pronounced for percent laboratory germination and percent hard seed,

Table 1. Heritabilty estimates for different groups of characters over environments and cropping system in soybean

Character	Environments				
	Palampur monoculture	Palampur inter-cropping	Solan	Katrain	Kangra
Seed yield and its components					
Seed yield/plant (g)	24.2	19.5	37.8	2.5*	60.0
Pods/plant	8.8*	11.2*	60.6	40.2	2.6*
Pods/main stem	47.5	0.0*	53.1	75.4	30.2
Pod length (cm)	30.5	0.2*	47.3	34.4	42.0
Seeds/pod	19.9	1.1*	15.6	0.0*	32.1
Seed quality traits					
Percent lab. germination	5.9*	4.6*	7.9*	26.4	33.8
Percent hard seed	6.6*	41.6	26.3	21.7	39.9
100-seed weight (g)	78.1	42.1	81.2	77.4	57.7
100-seed volume (cc)	76.2	45.0	80.8	80.4	58.1
Seed density (gm/cc)	68.2	55.3	51.9	80.9	70.9
Seed specific gravity index	60.6	29.9	45.2	71.2	68.6
Structural components					
Plant height (cm)	35.4	26.5	68.6	76.6	32.9
Branches/plant	33.7	0.1*	37.0	34.5	56.9
Nodes/main stem	25.0*	2.9*	54.8	65.5	65.7
Petiole length (cm)	--	0.0*	40.5	29.3	--
Phenological traits					
Days to first flower	93.7	--	77.8	--	96.2
Days to maturity	89.2	62.7	24.7	9.43*	62.7
Physiological trait					
Pod potential/node	30.5	0.4*	0.1*	--	47.3

*Nonsignificant differences among genotypes as per the analysis of variance in the respective environment.

whereas the drastic influence of cropping system on heritability was evident for all the quality traits, namely, percent lab. germination, percent hard seeds, 100-seed weight, 100-seed volume, seed density, and seed specific-gravity index. The environmental status had, however, no relationship with the heritability of quality traits as well. It is interesting to note that at the same location, the heritability of percent hard seeds has enhanced from

6.6% in monoculture to 41.6% in intercropping system and for other quality traits, the heritability was considerably reduced under intercropping system as compared to monoculture. In general, the heritability estimates with respect to 100-seed weight, 100-seed volume, seed density and specific-gravity index, were consistently high over locations.

For structural components, namely plant height, branches/plant, nodes/main stem and petiole length, though both locations and cropping system had influenced the heritability estimates, however, influence of the latter was much more, reducing the heritability to zero level. For these traits also there was no apparent relationship of the environmental status with heritability except for petiole length where favorable environment exhibited higher heritability.

For days to first flower, though, there was consistency in heritability over locations but the heritability estimates for days to maturity greatly fluctuated over environments and cropping system. For pod potential per node, both environments and cropping system influenced the heritability estimates.

Conclusion. In general, both environment and cropping system exhibited considerable influence for majority of the traits studied and there was no apparent relationship between heritability estimates and environmental status. With exception of percent hard seed, heritability estimates were considerably reduced under intercropping system as compared with monoculture.

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8) Association of leaf and root characteristics among themselves and with seed yield, structural, physiological and phenological traits in soybean

Introduction. The variation present for leaf and root characteristics has been reported earlier and in this communication the association of these traits with seed yield and other traits is being presented.

Materials and methods. Materials used in this study and design of experiment were the same as reported by Gupta et al. (1981) and in the earlier communication on variation for leaf and root characteristics. The data were further analyzed for estimating the correlation coefficients at phenotypic and genotypic level.

Results and discussion. Though the correlation coefficients at genotypic, phenotypic and environmental level were estimated among root and leaf characteristics themselves and also with other traits in the material mentioned earlier (Gupta et al., 1981), the only significant correlation coefficients at phenotypic level have been given in Table 1, as the genotypic correlation coefficients, in general were higher than phenotypic correlations, indicating inherent association among various traits. It can be seen from Table 1 that, irrespective of the environment, leaf potential per plant is positively associated with pods per plant, primary branches per plant and nodes per main stem. Leaf potential per plant (a measure of source) has also shown a positive association with pod potential per node (a measure of sink) at Solan. However, pod potential per node could not be studied at Katrain. There is also positive association between leaf potential per plant and unit leaf area. Leaf area, interestingly, is also positively associated with yield, petiole length and plant height at both locations. However, both leaf potential per plant and leaf area have shown strong positive association with seed yield, pods per plant, plant height, petiole length, days to first flowering, days to maturity and pod potential per node at Solan. The association observed at Katrain has to be viewed cautiously because there is absence of genotypic differences for yield, leaf potential per plant and leaf area. Hence, if one considers the relationship of these characters at Solan, it can be concluded that there is a good correlation between source and sink in the present material and an ideal plant as described under ideotype for wider adaptability (Garg, 1979) also needs to have high leaf potential per plant and more unit leaf area, besides larger petiole responding to changing environments and higher number of nodes per plant, thus leading to high yield. Earlier reports also indicate varietal differences in net photosynthesis as a result of differences in total leaf area per plant (Ozima, 1972).

The larger petiole length and higher number of nodes would provide more aerial display for leaves and thus reduce the mutual shading effect due to high leaf potential and per-unit leaf area. The reduction in yield in spite of high leaf potential and leaf area has been recorded earlier mainly due to mutual shading of leaves (Wallace and Munger, 1965; Adam, 1975). The poor yield obtained for pine-shaped mutant having more petiole length at the base as compared to tips (Tattersfield and Williams, 1979) might be due to less leaf potential or less unit leaf area.

For the root characteristics studied in the present investigation, namely nodules per plant, nodule dry matter per plant and root dry matter per plant, the varietal differences appear to be marked due to larger environmental influences. However, all the three root characteristics are positively associated with seed yield, pods per plant, nodes per main stem, petiole length and days to first flowering.

Table 1. Significant associations of leaf and root characteristics with yield and other traits in soybean

	Leaf characteristics (at Solan)		Root characteristics (at Palampur)-monoculture		
Characters	Leaf potential/ plant	Leaf area	Nodules/ plant	Nodule dry matter/ plant	Root dry matter/ plant
Seed yield/plant (g)	0.65	0.40	0.31	--	0.37
Pods/plant	0.78	0.45	0.35	0.35	0.44
Pods/main stem	0.48	--[a]	--	--	--
Plant height (cm)	0.56	0.43	--	--	--
Primary branches/plant	0.61	--	--	--	0.41
Petiole length (cm)	0.51	0.39	--	--	--
Nodes/main stem	0.54	--	0.41	0.40	0.46
Days to first flowering	0.39	0.39	0.38	0.35	0.49
Days to maturity	0.33	0.34	--	--	--
Pod potential/node	0.41	0.60	--	--	--
Leaf potential/plant	--	0.36	--	--	--
Leaf area	0.36	--	--	--	--
Nodules/plant	--	0.42	--	0.73	0.66
Nodule dry matter/plant	--	--	0.73	--	0.70
Root dry matter/plant	--	--	0.66	0.70	--

[a] Correlation not calculated or nonsignificant at 5%.

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9) Variation and heritability for leaf and root characteristics in soybean, across locations

Introduction. Generally yield of soybean has been reckoned in terms of yield components like pods per plant but it is only one aspect of an overall allometry for enumerating the soybean plant. The other components which need attention are the physiological and root characteristics, which remained ignored so far, in breeding programs (Adam, 1975). To surpass the yield plateau in soybean, it is imperative that we pay due attention to these traits with a view to increase the photosynthetic efficiency and translocation activities through the genetic improvement of leaf and root characteristics. Hence, the present study was conducted to obtain information on nature of variation and heritability of these traits in soybean.

Materials and methods. Materials used in this study and design of experiment were reported by Gupta et al. (1981), except that in this study, data were obtained only from two locations -- Solan and Katrain (for leaf potential per plant and leaf area), and from Palampur and Solan (for nodules/plant). Nodule dry weight and root dry weight were recorded only at Palampur. Leaf characteristics were recorded at pod-formation stage and root characteristics were taken at 50% flowering stage.

Results and discussion. Estimates of means, range, variances and coefficient of variation (phenotypic, genotypic, environmental) and heritability for leaf potential/plant leaf area, nodules per plant, nodule dry weight per plant and root dry weight per plant are given for locations in Table 1. The available information on leaf characteristics with respect to variation and heritability is limited, however, Lal and Haque (1972) reported high estimates of genotypic coefficients of variation for number of leaves per plant and total leaf area. The estimates of range, genotypic coefficient of variation and heritability for number of leaves per plant were 11.67-86.0, 46.67 and 89.28%; and for total leaf area were 142.83-853.50, 42.49 and 88.19%, respectively, as reported by Lal and Haque (1972). In the present study, for leaf potential per plant (no. of leaves/plant), the range recorded at both the locations, Solan and Katrain, was 17.0-55.2 and 40.8-106.2, respectively, indicating the influence of location on the expression of this trait. The coefficient of variation at genotypic level at Solan was about twice that of Katrain and higher heritability to the extent of 45% was also recorded at Solan, which was, however, lower in magnitude than the earlier report (Lal and Haque, 1972). However, lower magnitude of genotypic variance than environmental variance at both the locations, indicated the larger

Table 1. Estimates of mean, range, variances (phenotypic, genotypic, environmental), coefficients of variation (genotypic, phenotypic, environmental) and heritability for leaf and root characteristics

Character	Location	Mean $\pm$ S.E.	Range
Leaf potential/plant	Solan	30.37$\pm$4.12	17.00-55.20
	Katrain	69.45$\pm$9.02	40.80-106.20
Leaf area	Solan	55.87$\pm$6.98	32.435-96.645
	Katrain	44.75$\pm$4.33	29.196-65.183
Nodules/plant	Palampur	133.42$\pm$29.63	64.5-290.0
	Solan	46.44$\pm$18.48	3.00-131.0
Nodules dry weight/plant	Palampur	0.4192$\pm$0.0885	0.220-0.940
Root dry weight/plant	Palampur	0.8285$\pm$0.1956	0.300-1.825

*Significant at 5% level.

Variances			Coefficient of variation			
Phenotypic	Genotypic	Environmental	Phenotypic	Genotypic	Environmental	Heritability
62.10	28.16	33.94	25.95	17.47	19.19	45.34*
198.31	35.58	162.73	20.27	8.58	18.36	17.94
136.75	39.26	97.49	20.93	11.22	17.67	28.71*
43.07	5.63	37.44	14.67	5.30	13.67	13.07
1998.43	243.10	1755.33	33.51	11.69	31.40	12.16
835.45	152.12	683.33	62.24	26.56	56.29	18.21
0.01588	0.00021	0.01567	30.07	3.49	29.86	1.35
0.07837	0.00188	0.07649	33.79	5.24	33.38	2.40

influence of unknown factors. The influence of location was also considerable as the heritability at one location was two and a half times more than the other. For leaf area, mean and range were higher at Solan than those of Katrain. Lower estimates of error variances for this trait also indicated its sensitivity to unknown factors. For this trait, also, the magnitude both genotypic coefficient of variation and heritability estimates at Solan were more than twice those at Katrain, indicating the influence of location on these estimates. In general, a wide range of variation was recorded both for leaf area and leaf potential among genotypes at both the locations, however, the significant differences among genotypes were observed at Solan location.

The information on root traits is also limited. However, Mitchell and Russell (1971) reported a range of 0.4 to 2.0 gm per plant root dry weight, recorded 60 days after planting and presence of varietal differences for this trait. The range recorded in the present study for this trait was from 0.30 to 1.82 gm per plant. The heritability for root dry weight was, however, very low due to high coefficient of variation at environmental level. For nodules dry weight, also, similar situation was observed with respect to range, variation and heritability. Nodules per plant, which were counted at two locations, namely Palampur and Solan, the estimates of mean and range as well as coefficient of variation at genotypic, phenotypic and environmental level and heritability were higher at Solan. However, at both the locations, high magnitude of variance and coefficient of variation at environmental level, indicated the greater influence of environment due to unknown factors, one of them might be sampling error. In general for root characteristics, a wide range among the genotypes studied was recorded, though heritability estimates remained low due to greater influence of unknown factors.

Conclusion. Wide range of variability is present for leaf and root characteristics, which is, however, greatly influenced both by location and some unknown factors and leaf characters had comparatively higher heritability than that of root characteristics. Therefore, it would be possible for a breeder to direct his selection at least for leaf characteristics, leading to higher photosynthetic activity and enhanced yield.

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10) Genetic, altitude and climatic effects on seed yield and germinability traits in soybean

Introduction. In soybean production, the lack of varieties having good seed quality, with respect to germinability, is an important constraint. Though several authors (Johnson et al., 1955; Schutz and Bernard, 1967; Shorter et al., 1977) have reported the role of genotype, environment, and genotype x environmental interaction for seed yield and seed weight, yet such information in respect to seed quality traits, such as percent hard seeds and germinability is meager (Gupta and Garg, 1980). Therefore, in the present study, an attempt has been made to obtain information on the role of genetic, altitude and other climatic factors on seed yield and seed quality traits.

Methods and materials. Sixty varieties of soybean were grown in completely randomized block design with two replications at Palampur, Kangra and Kulu having altitudes of 1300, 700 and 1300 m, respectively, during Kharif, 1973. The average monthly meteorological observations for the growing period of soybean in respect to different locations are given in Table 1. The plot size was 2.7 sq. m. at Kangra and Kulu, while it was 3.0 sq. m. at Palampur. Data were recorded for seed yield (kg/ha), 100-seed weight (g), percent hard seeds and germinability. Days taken to 70% germination was taken as the criterion for germinability. For this purpose, a sample of 100 seeds was kept in the seed germinator at 90°F. The count for the germinated seeds was made after 24 hours. Seeds that did not absorb moisture in the germination test were counted and expressed as percent hard seeds. The combined analysis of variance over locations was done and coefficients of variation, heritability and the expected genetic advance were also calculated. Locations were measured for their potential as per Finlay and Wilkinson (1963) by estimating environmental index for each location.

Results and discussion. Combined analysis of variance (Table 2) over locations indicated significant mean squares due to genotypes, locations, and genotype x location interactions for seed yields, 100-seed weight and percent hard seeds. In case of days to 70% germination, mean squares due to genotypes and locations were only significant, indicating the absence of genotype x location interaction.

On partitioning the total variability, it was found that all the characters except germinability had the highest coefficient of variation for genotype x location interaction (Table 3). The coefficient of variation at genotypic and location level was considerably less for these characters. Among all the seed characters studied, percent hard seeds exhibited the highest genotype and genotypic x location coefficient of variation.

Contribution of each component of variability for the expression of seed yield and other characters is given in Table 4. Genotype x location interaction component has predominantly contributed (66 to 76%) for seed yield and 100-seed weight, whereas, for percent hard seed, its contribution is around 32%. In the present material, genetic component also contributed from 20-30% for seed yield, percent hard seed and germinability. It is interesting to note that for 100-seed weight, genetic component is playing the least role and more than 90% variation has been caused by genotype x location interaction and location components of variability.

Table 1. Average (over 5-10 years) monthly meteorological observations during growing period of soybean at different locations

Meterological observation	Location	Months					
		June	July	Aug.	Sept.	Oct.	Nov.
Average mean temperature (°C)	Palampur	25.7	24.8	24.7	22.9	20.9	16.6
	Kangra	26.5	25.5	25.0	24.3	21.3	15.7
	Kulu	24.3	23.8	24.0	22.0	19.5	15.4
Average minimum temperature (°C)	Palampur	21.7	22.1	22.1	19.7	17.1	11.9
	Kangra	17.5	21.3	21.0	18.8	14.2	8.4
	Kulu	18.5	17.7	18.5	15.1	10.6	5.1
Average maximum temperature (°C)	Palampur	29.6	27.5	27.2	26.1	24.6	21.3
	Kangra	35.5	29.7	29.0	29.7	28.4	23.0
	Kulu	30.1	29.0	29.5	28.9	28.4	25.7
Average rainfall (mm)	Palampur	367.2	700.0	800.0	258.6	43.4	12.0
	Kangra	136.3	402.3	649.9	141.1	33.5	7.8
	Kulu	25.3	60.1	58.2	19.7	10.4	1.9
Average relative (%) humidity	Palampur	61	78	85	78	62	55
	Kangra			Not available			
	Kulu	85	86	85	85	77	73
Average rainy days (no.)	Palampur	2.0	5.3	6.6	1.9	1.0	0.1
	Kangra	7.4	12.3	16.3	6.2	1.5	1.0
	Kulu	1.7	4.0	3.6	2.0	0.8	0.1

Table 2. Combined analysis of variance over environments

Source	Degrees of freedom	Mean sum of squares due to: Seed yield (kg/ha.)	100-seed weight (gm)	Percent hard seed	Days to 70% germination
Genotype	59	466138.4*	23.3*	28.55*	0.77*
Environments	2	13249800.0*	332.5*	103.85*	17.40*
Genotype x Environment	118	205788.6*	23.0*	9.63*	0.19 } 0.23
Pooled Error	177	5033.0	0.88	3.12	0.25

*Significant at the 5% level.

Table 3. Components of variance and coefficient of variation from combined analysis over locations

Components of variance & C.V.	Character: Seed yield (kg/ha.)	100-seed wt. (gm)	% hard seeds	Days to 70% germination
Genotypic variance	86783.27	0.5	3.15	0.09
Locational variance	9326.59	2.58	0.78	0.14
Genotypic x location interaction variance	102869.14	11.06	3.26	--
Error variance	50.33	0.88	3.12	0.23
Genotypic coefficient of variance	13.5	1.6	57.2	7.30
Genotypic x location C.V.	20.8	23.9	58.1	--
Locational C.V.	6.2	11.5	28.5	9.20
Experimental Error C.V.	0.4	6.7	56.9	11.60

Table 4. Percent contribution of each component of variance for the expression of seed yield and its quantity characters

Character	Components of variance			
	σ^2_g	σ^2_{gl}	$\sigma_{e_1}^2$	σ_e^2
Yield (kg/ha)	27.88	66.09	5.99	0.032
100-seed weight (gm)	0.34	75.91	17.70	6.04
Percent hard seeds	30.57	31.56	7.61	30.25
Days to 70% germination	19.44	--	30.89	49.6

Estimates of heritability and genetic advance expressed as percent of mean at different locations and after eliminating locations effects on genotypes are given in Table 5. At each location, a high heritability associated with high genetic advance was noticed for all the traits. The results suggested the presence of additive genetic effects at all the locations. However, after eliminating the location effects on genotypes, the magnitude of both heritability and genetic advance decreased for seed yield, percent hard seeds and days to 70% germination. In case of 100-seed weight, the estimates of heritability and genetic advance were drastically reduced to the lowest level. The results suggested the influence of the locations on these parameters.

In order to quantify the environments, estimates of environmental index were calculated as the deviation of such location mean from grand mean (Table 6). It can be seen that Kangra and Palampur were the best locations for the expression of seed yield, while Palampur appeared to be the best for 100-seed weight. Kulu was the best environment for germinability. The frequency of percent hard seeds was the highest at Kangra. The study of this information reveals that for seed yield apart from altitude, other climatic factors such as humidity, temperature and rainfall also play an important role (Table 1). The low yield of soybean genotypes at Kulu appears to be due to the low mean temperature during the growth period and more specifically after September when the seeds develop. For the expression of higher 100-seed weight, comparatively high rainfall and relatively low maximum temperature at Palampur during seed development appear to be responsible. The lower elevation and comparatively higher maximum temperature at Kangra produce more hard seeds. Low temperature and less rainfall during seed development appear to be responsible for better germinability at Kulu.

Table 5. Estimates of heritability and genetic advance expressed as percent of mean at different locations as well as after eliminating locational effects on genotypes

Character	Estimate of	Kangra	Palampur	Kulu	After eliminating location effects on genotypes
Seed yield (kg/ha)	Heritability	72.17	61.21	36.08	29.60
	Genetic advance as % of mean	82.31	54.59	125.91	17.23
100-seed weight (gm)	Heritability	95.15	92.83	84.94	0.40
	Genetic advance as % of mean	35.61	43.47	42.20	2.05
Percent hard seeds	Heritability	84.12	77.62	85.79	33.00
	Genetic advance as % of mean	218.72	199.43	263.23	67.68
Days to 70% germination	Heritability	47.16	58.97	36.08	28.10
	Genetic advance as % of mean	70.72	75.84	51.75	32.73

Table 6. Estimates of environmental index

	Environments			
Character	Palampur	Kangra	Kulu	Grand mean
Seed yield (kg/ha)	+83.7	+87.7	-171.3	1541.3 $\pm$.64
100-seed weight (gm)	+ 2.7	- 1.4	- 1.3	13.9 $\pm$.085
Percent hard seeds	- 0.5	+ 1.5	- 1.0	3.1 $\pm$.14
Days to 70% germination	- 0.3	- 0.3	+ 0.6	4.1 $\pm$.04

Summary. Fifty exotic germplasm lines, along with ten extensively evaluated varieties of soybean, were evaluated in a replicated trial at three locations having altitudes 700 to 1300 m above mean sea level, in Himachal Pradesh (India); for seed yield, seed size, percent hard seeds and germinability to understand the nature and magnitude of variation present for these characters. Significant differences were observed among genotypes for characters studied. Genotype x environment interaction was significant for seed yield, 100-seed weight and percent hard seeds. Environmental influence was also significant for all the traits. Highest C.V. at genotypic, genotype x location and location level was observed for percent hard seeds. Estimates of heritability and genetic advance were influenced by location for all the characters studied. After eliminating the location effect, the highest heritability was recorded for percent hard seeds, followed by seed yield and germinability; and 100-seed weight was the most influenced by environments for genetic parameters. Except germinability, the expression of variation for all other traits was mainly due to genotype x location effects, besides genetic and location. For seed weight, it was mainly genotype x location interaction that accounted for 76% of the total variation. For germinability, the effect of altitude was alone appreciable besides genetic component. For seed yield, Palampur and Kangra were the best environments. For seed weight, Palampur was the best, whereas at Kangra, the frequency of hard seeds was maximum. Kulu Valley with subtemperate climate was best for germinability.

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11) Correlation among seed yield, seed quality and nutritional traits in soybean

Introduction. In the present communication, the information obtained on correlations among 14 traits related to seed yield, seed quality and nutrition in soybean germplasm has been discussed. The information on the nature of variation for these traits in the above material has been reported earlier (Rana et al., 1981).

Materials and methods. The materials and methods were reported earlier by Rana et al. (1981). Correlation coefficients were, however, estimated among the 14 traits on the basis of unadjusted means of 250 germplasm lines using the standard formula.

Results and discussion. Estimates of correlation coefficients among the 14 characters, namely, seeds per plant, yield per plant, seed weight, 100-seed volume, water absorption, percent germination, percent hard seeds, crushing hardness, percent protein, percent potassium, percent phosphorus, percent moisture, boldness index and specific-gravity index, calculated on the basis of observed mean values of 250 test cultures, are given in Table 1.

Out of the 91 possible combinations among the 14 characters studied, 37 combinations showed significant correlation coefficients.

With respect to seeds per plant, boldness index, specific-gravity index and 100-seed volume, yield per plant has shown strong positive association indicating, thereby, that seed yield in soybean can be improved by making selections on the basis of specific-gravity index, which, in turn, reflects seed weight, seed boldness and 100-seed volume. Interestingly, these traits bear significant positive correlation among themselves. Positive association of seed weight with seed yield in soybean has also been documented earlier (Johnson et al., 1955; Keller et al., 1978). However, a few workers (Kwon and Torrie, 1964; Hartwig and Edward, 1970; Shettar et al., 1978) have reported absence of any association of seed weight with seed yield or its negative association. Correlation of seed number with seed yield has been very well documented earlier (Leffel and Henson, 1961; Gopani and Kabaria, 1970; Jaranowski et al., 1980). With respect to 100-seed volume and specific gravity index some workers have reported absence of any association with seed yield (Smith and Weber, 1968; and Gupta and Garg, 1980).

Among all the major yield contributing seed traits, breeding for specific-gravity index, specifically following the stratified method of mass selection would help in simultaneously improving the seed size and seed yield. Interestingly, both specific-gravity index and seed yield are positively associated with water absorption capacity of seed which in the present study has been taken as one of the criteria of good cooking quality -- the higher the water absorption capacity of a genotype, the better the cooking quality of it. Therefore, the present correlation analysis indicates that seed yield, seed size and cooking quality in soybean can be improved simultaneously. Information on the relationship of water absorption with seed yield and other seed quality in the literature is as good as nil.

In the present material, seed yield has not been found to bear any relationship with percent protein, percent potassium, percent phosphorus, percent moisture, percent hard seeds and percent germination. With respect to percent

Table 1. Estimates of correlation coefficient among various characters studied on the basis of 250 test cultures

Characters	Seeds per plant	Yield per plant (gm)	Seed weight (mg)	100-seed volume (cc)	Water absorption (cc)	Percent germination	Percent hardness	Crushing hardness (kg)	Percent protein	Percent potassium	Percent phosphorus	Percent moisture	Boldnsss index
	1	2	3	4	5	6	7	8	9	10	11	12	13
Yield/plant (gm)	.77*												
Seed wt (mg)	-.16*	.44*											
100-seed volume (cc)	.02	.26*	.38*										
Water absorption	-.23*	.30*	.35*	.35*									
% germination	.26*	.07	-.24*	-.04	-.23*								
% hard seeds	-.03	-.10	-.11	-.07	-.30*	-.24*							
Crushing hard-ness (kg)	-.20	-.13*	-.01	.08	-.08	-.20	.22*						
% protein	-.03	-.06	-.02	.04	.03	.05	.02	.13*					
% potassium	-.06	-.01	.88	.07	.04	-.05	-.05	-.04	.04				
% phosphorus	.05	-.06	-.11	-.04	-.22*	.13*	.05	-.12*	.04	-.06			
% moisture	.05	.01	-.06	-.05	-.11	-.08	.11	-.14	-.05	-.02	.11		
Boldness index	-.13*	.40*	.86*	.35*	.78*	-.21*	-.08	-.05	-.01	-.01	-.16*	-.05	
Specific gravity index	.12*	.29*	.27*	.14*	.16*	.12*	-.08	-.09	-.01	-.05	-.04	-.01	.39*

*Significant at the 5% level.

potassium, percent phosphorus, percent moisture and crushing hardness, there is no information available in the literature on their association with yield. Garg (1979) reported percent hard seeds to have no association with yield, while Klykov (1952) found a positive association of grain yield with number of hard seeds. Earlier workers have also reported absence of any relationship between seed yield and percent germination (Singh et al., 1979; Garg, 1979). Another important character investigated in the present study is crushing hardness as an index of cooking quality. It has shown negative association with yield. Though this correlation is significant, yet it accounts for only 1.7% of the total variation in yield. As no information is available in literature on this association, it requires further study.

With respect to associations of percent protein and seed yield, the reports in the literature are conflicting ones, some showing no correlation (Smith, 1967); some giving negative association (Arora et al., 1970; Kwon and Torrie, 1964); and others giving positive relationship (Brim and Burton, 1979). Shannon et al. (1972) have reported positive and negative associations of protein with yield in two different populations. Percent protein has been found to be positively associated with crushing hardness in the present material as also reported earlier by Gupta et al. (1980). However, protein content has not shown any association with percent potassium, percent moisture, boldness index, specific gravity index, seed weight, 100-seed volume, water absorption and number of hard seeds in the present study. Correlation of protein content with the content of phosphorus, potassium, and moisture and capacity of water absorption does not seem to have been studied earlier as there are no reports to this effect in the literature. Seed size, in the literature, has been reported to be positively correlated with high protein content (Fehr and Weber, 1968). Percent protein has been reported to have positive correlation with specific gravity (Hartwig and Collins, 1962; Fehr and Weber, 1968; Kwon et al., 1971) though there is no association between the two in the present material. The probable reason for the contradictory findings in the present material may be the extraordinarily large number of genotypes varying in seed weight, seed volume, and boldness index, which is further confirmed by the positive association of specific-gravity index, with seed weight, seed volume and boldness index recorded in the present material.

Another important character studied is the percent germination, in which, due to high magnitude of block environmental effects, the analysis of variance did not show significant difference among genotypes, yet the wide range of variation observed (18 to 98%) warrants the consideration of this trait in relation to others. Percent germination is positively associated with seeds per plants, but interestingly had no association with yield per plant, 100-seed volume, percent protein, percent potassium and percent moisture. It is interesting to note that germination exhibited positive association with specific gravity index and phosphorus content. Such information was not available in the literature. However, percent germination is negatively associated with boldness index, crushing hardness, percent hard seeds, water absorption and seed weight. With respect to relationship of germinability with crushing hardness, boldness index and water absorption, this is the first report. Negative association between germination percentage (both under laboratory as well as field conditions) and seed size has been widely reported (Edward and Hartwig, 1971; Paschal and Ellis, 1978; Singh et al., 1978). Johnson and Leudders (1974) and Garg (1979) have reported absence of any associations between seed size and percent germination, while positive correlation between the two parameters has been reported by Burris et al. (1971) and Godey et al. (1974). It appears that, for having high germinability, one should select genotypes having high specific-gravity index, high phosphorus content, on the one hand having low seed weight, low water absorption capacity, less hard seeds, less boldness index and low crushing hardness. Negative association between crushing hardness and percent moisture as well as between phosphorus content and boldness index is being reported for the first time consequent upon the findings of the present investigation.

Conclusion. Correlation analysis indicated that specific gravity index can be used effectively for improving seed yield in soybeans, but for improving seed germinability besides specific-gravity index, one has to breed for high phosphorus content but with lesser hard seeds, low crushing hardness, low water absorption capacity and smaller seed size.

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